Propagation-Based Phase-Enhanced Imaging

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Introduction

There are currently three techniques to accomplish phase-enhanced or phase-contrast imaging: x-ray interferometry, angle deflectometry and Fresnel diffraction. X-ray interferometers are capable of directly measuring the phase of the sample. However, x-ray interferometers are extremely sensitive devices with very low beam transmission and the usable sample sizes are usually limited to about 10 mm.[1,2] Furthermore, a certain amount of data processing is required before an image that resembles the sample can be obtained. With angular deflectometry (sometimes called "diffraction enhanced imaging"), analyzer crystals are used to detect the small angular deviations caused by the index of refraction variations within the sample.[3,4] While this method is easier than x-ray interferometry, it is only sensitive to one dimension (the scattering plane), and sample scanning is required. The technique discussed here is known as a "propagation-based" phase-enhanced imaging.[5,6] It uses the incoming beam coherence and Fresnel diffraction to obtain phase-enhanced images. The advantages of this technique are (1) its simplicity and in-line geometry, (2) very high intensities because no x-ray optics other than an upstream monochromator is required, and (3) the ability to image large samples.

Methods and Materials

With the propagation technique, the experimental setup is trivial. The experiments were performed at the SRI-CAT 1-ID undulator beamline. The sample was placed in the monochromatic beam at the 1-ID-C station, which is about 60 m from the source. The transmitted beam through the sample impinges on a scintillating crystal (Ce-doped YAG or CdW) to convert the x-rays to visible light, and a microscope objective was used to magnify the image for the CCD detector. To demonstrate the versatility of this technique a wide range of samples has been imaged, ranging from "soft" samples using 12 keV photons to "hard" samples using 90 keV photons.

Results

Figures 1-3 show images taken with the conventional absorption mode (a) and the phase-enhanced mode (b). Experimentally, the difference between these two modes is simply the distance between the sample and the detector. In the absorption mode, the detector was placed very close (~5 mm) to the sample while in the phase-enhanced mode, the detector was placed a certain distance (0.1 – 2.0 m) away. The field of view in these images is 1×1 mm^2. Figure 1 shows the image of a leaf taken with 10 keV photons, Fig. 2 shows the image of an aluminum crack test sample (schematic shown in Fig. 2c) taken with 30 keV photons, and Fig. 3 shows the images of a stainless steel gas nozzle (schematic is shown in Fig. 3c) taken with 70 keV photons. All the images were taken with about a 1 sec exposure and with the upstream monochromator highly detuned so as not to overwhelm the CCD detector. Furthermore, the undulator gaps were not optimized for the

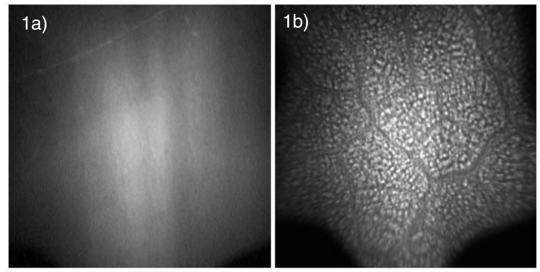
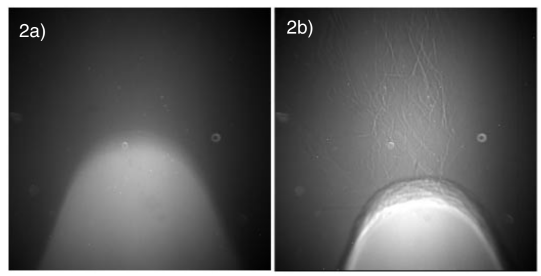


FIG. 1a (left). Absorption image of a leaf taken with 10 keV x-rays. FIG. 1b (right). Phase-enhanced image of a leaf taken with 10 keV x-rays.



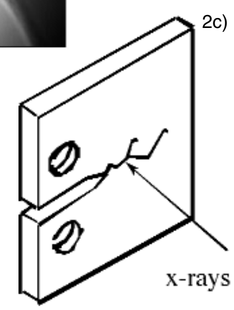
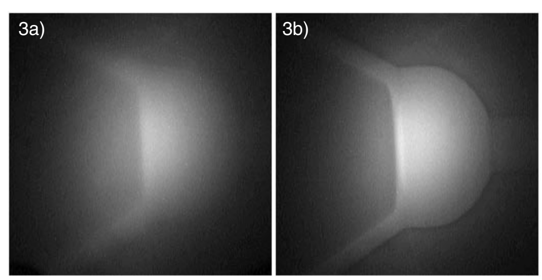


FIG. 2a (left). Absorption image of an aluminum crack test sample taken with 30 keV x-rays. FIG. 2b (right above). Phase-enhanced image of an aluminum crack test sample taken with 30 keV x-rays. FIG. 2c (right). Schematic of the aluminum crack test sample. The sample was 2.7 mm thick.



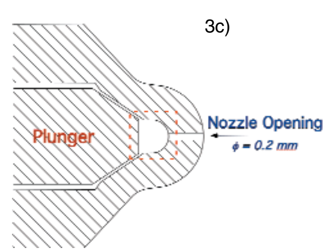


FIG. 3a (left). Absorption image of a stainless steel gas nozzle taken with 70 keV x-rays. FIG. 3b (right above). Phase-enhanced image of a stainless steel gas nozzle taken with 70 keV x-rays. FIG. 3c (right). Schematic of the stainless steel gas nozzle.

energies used. For all the cases shown here, there is clearly enough flux to obtain images with 1 ms or less exposures.

Discussion

The phase-enhanced images shown here were taken in the so-called “edge enhanced” regime. This is most obvious in Fig. 3. The edges of the plunger and the "reservoir" show increased or decreased intensities based on the details of the sample. Thus, it is easy to detect the various edges of the sample. The simplicity of this technique and the high flux available at the APS opens up the possibility of doing 1 ms or less time-resolved imaging. Another avenue of research is to combine this approach with tomography to yield a full phase reconstruction of the sample.[7] Both are currently being pursued.

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